



PMU Power Grid Coverage Group # SD0903

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Introduction

- ▶ Phasor Measurement Units(PMUs)
- ▶ Observability of an Electrical Grid
- ▶ Placement Algorithms
- ▶ Cost



Requirements

- ▶ Full Coverage
- ▶ (Sub)optimal Placement
- ▶ Researched Previous Published Algorithms
- ▶ Implementation of Algorithms
- ▶ Efficiency
- ▶ Conference Paper



Technical Content

- ▶ Algorithms

- ▶ Greedy
- ▶ Single Vertex
- ▶ Double Vertex
- ▶ A*
 - ▶ Depth Search Method
 - ▶ Restricted List Method

- ▶ IEEE Standard Test Bus Systems

- ▶ 2383 Test Bus System



Greedy Algorithm

▶ Principle

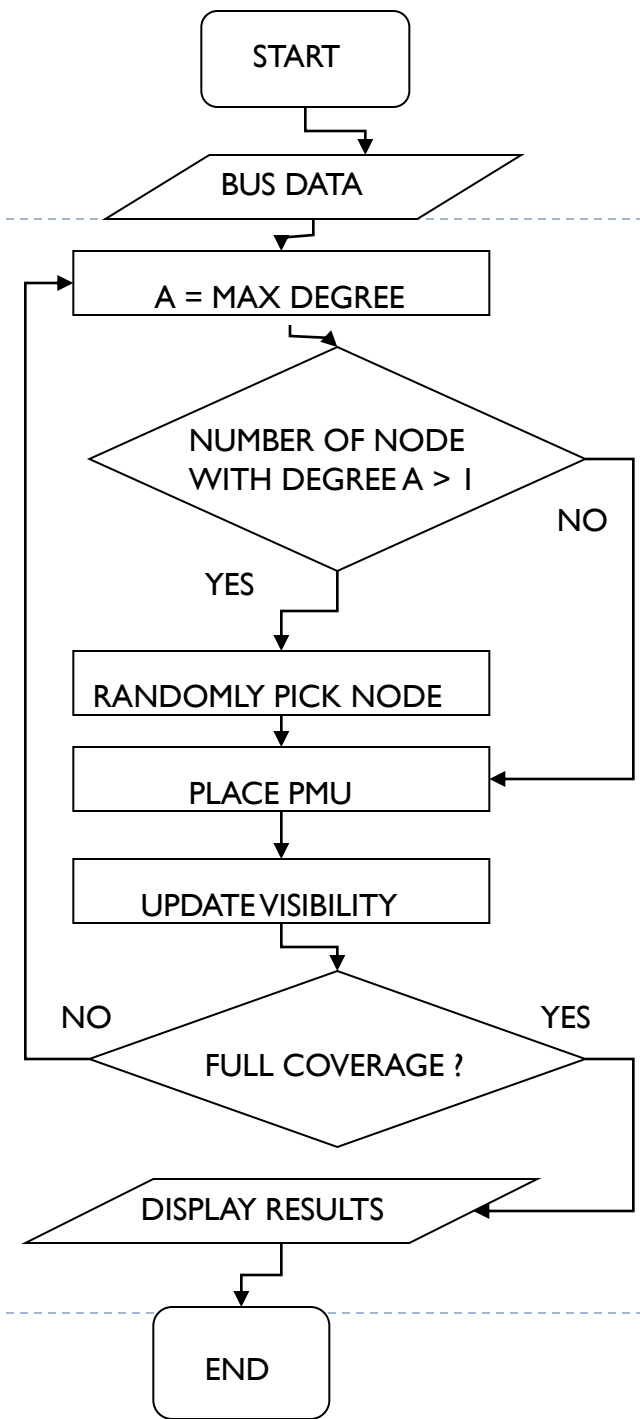
- ▶ Simple Heuristic

▶ Advantages

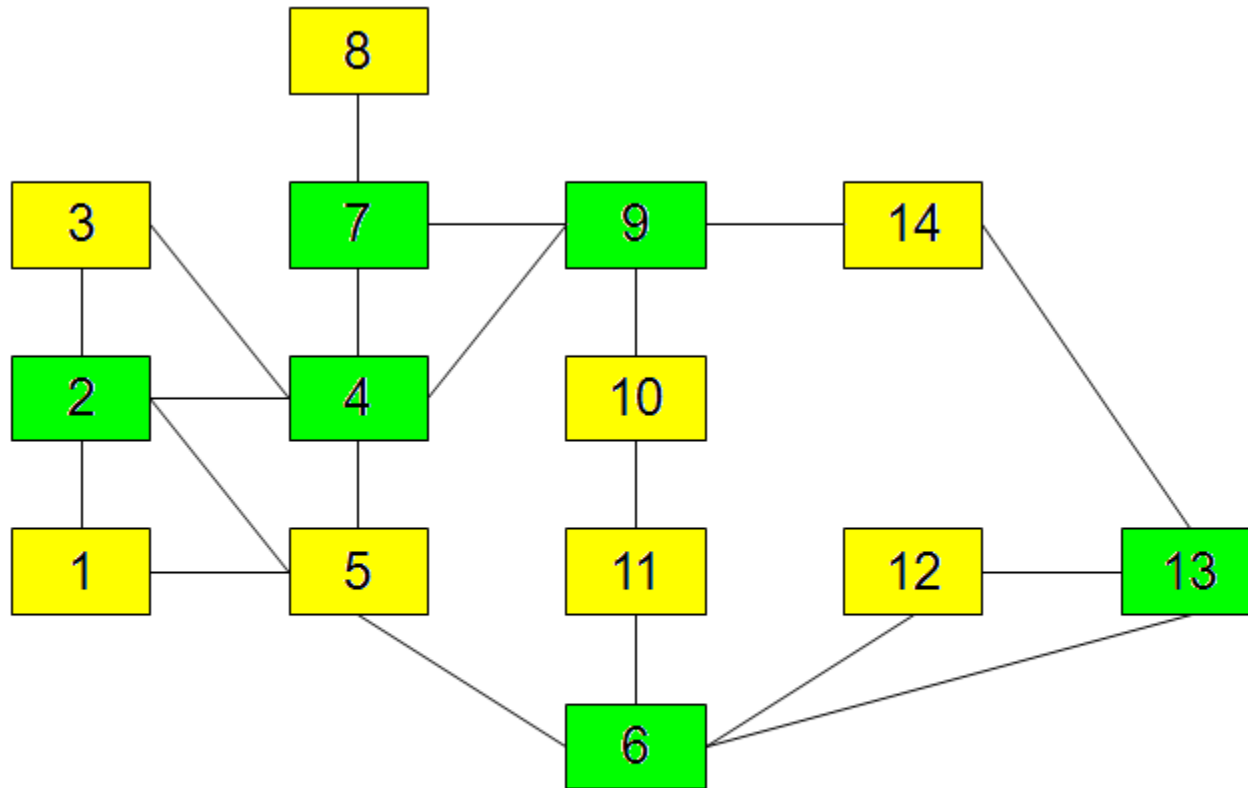
- ▶ “Greedy” Characteristic
- ▶ Time Efficient

▶ Disadvantages

- ▶ “Greedy” Characteristic
- ▶ Non-deterministic



Greedy Algorithm Test Case



Single Vertex Algorithm

▶ Principle

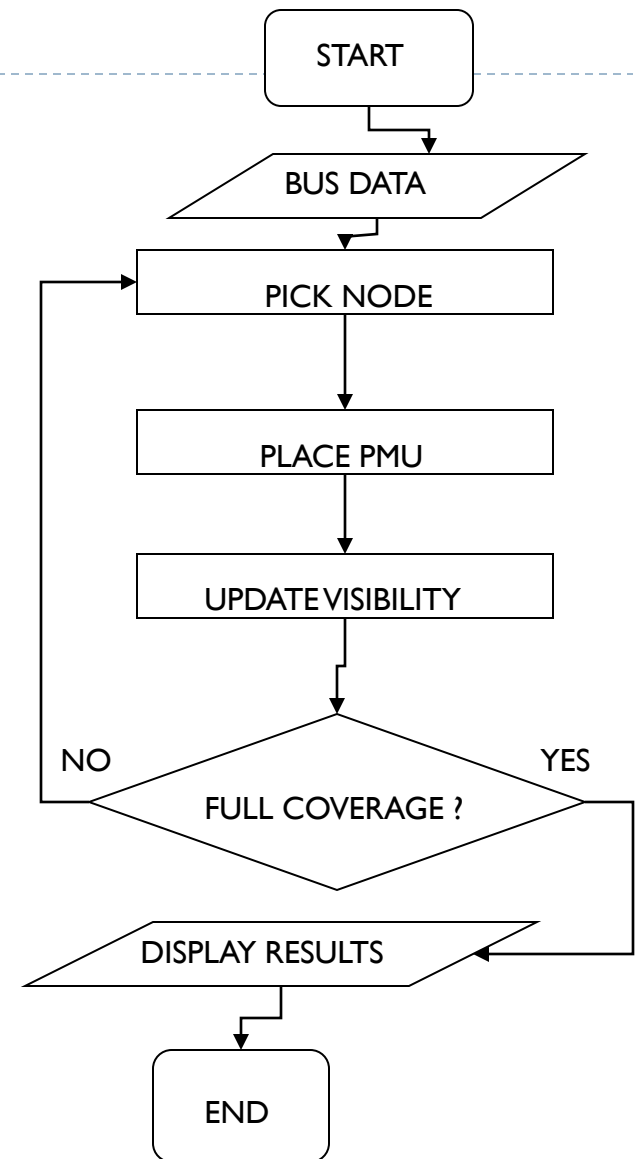
- ▶ Basic Implementation

▶ Advantages

- ▶ Time vs. Accuracy

▶ Disadvantages

- ▶ Non-deterministic
- ▶ Time Inefficient



Double Vertex Algorithm

▶ Principle

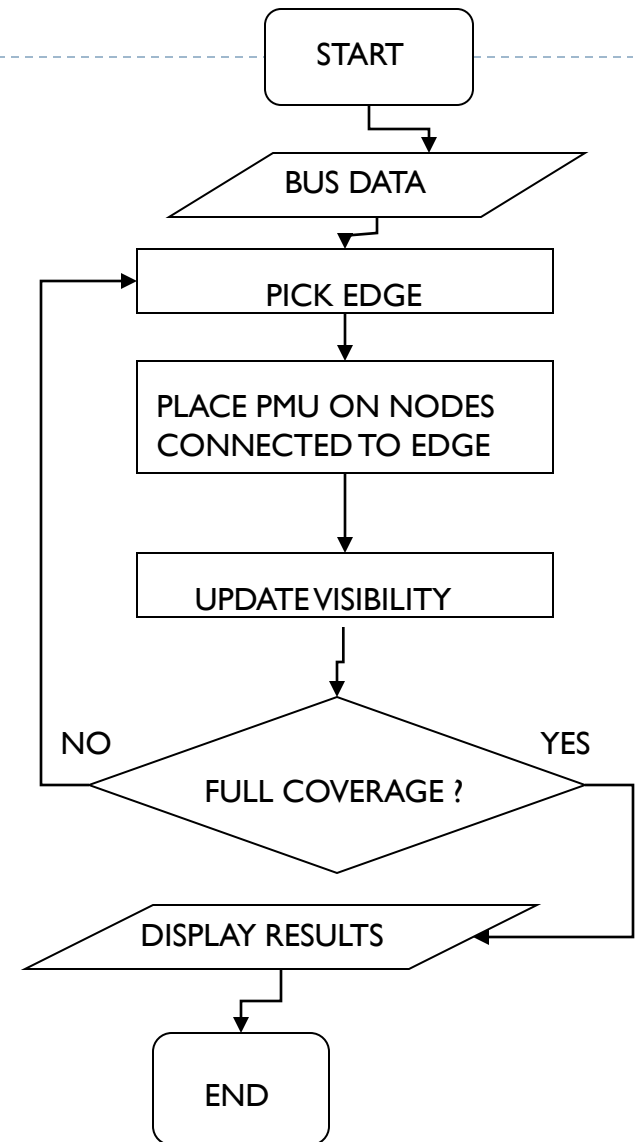
- ▶ Basic Implementation

▶ Advantages

- ▶ “Radial” Structure
- ▶ Time efficient

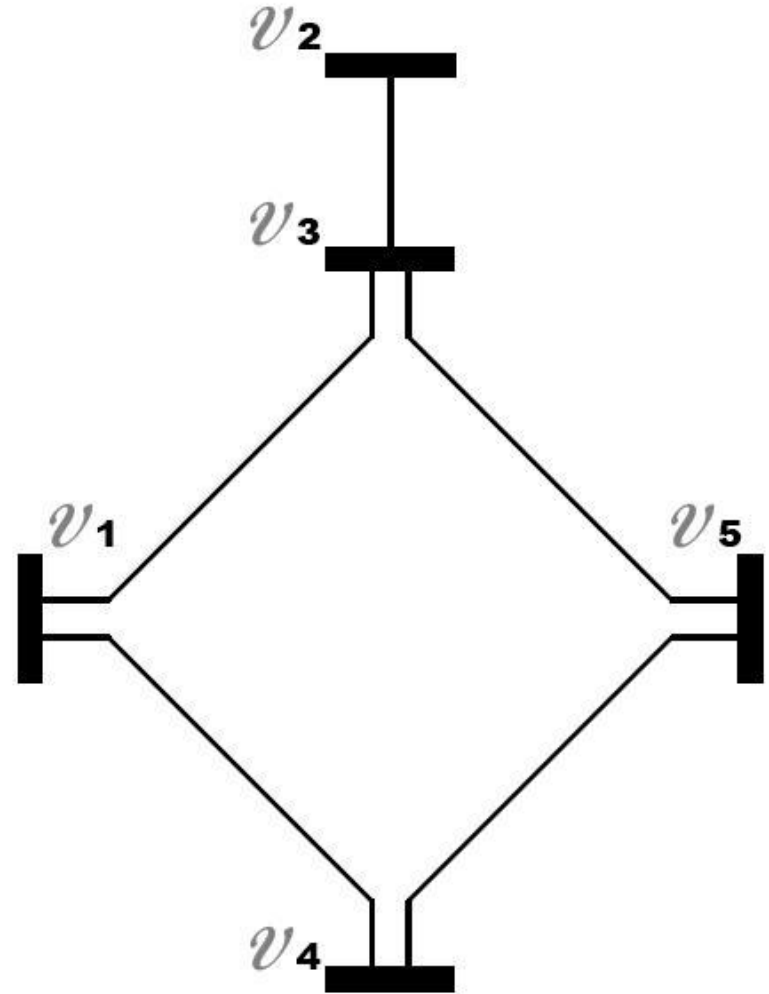
▶ Disadvantages

- ▶ Non-deterministic
- ▶ Overlap of Coverage

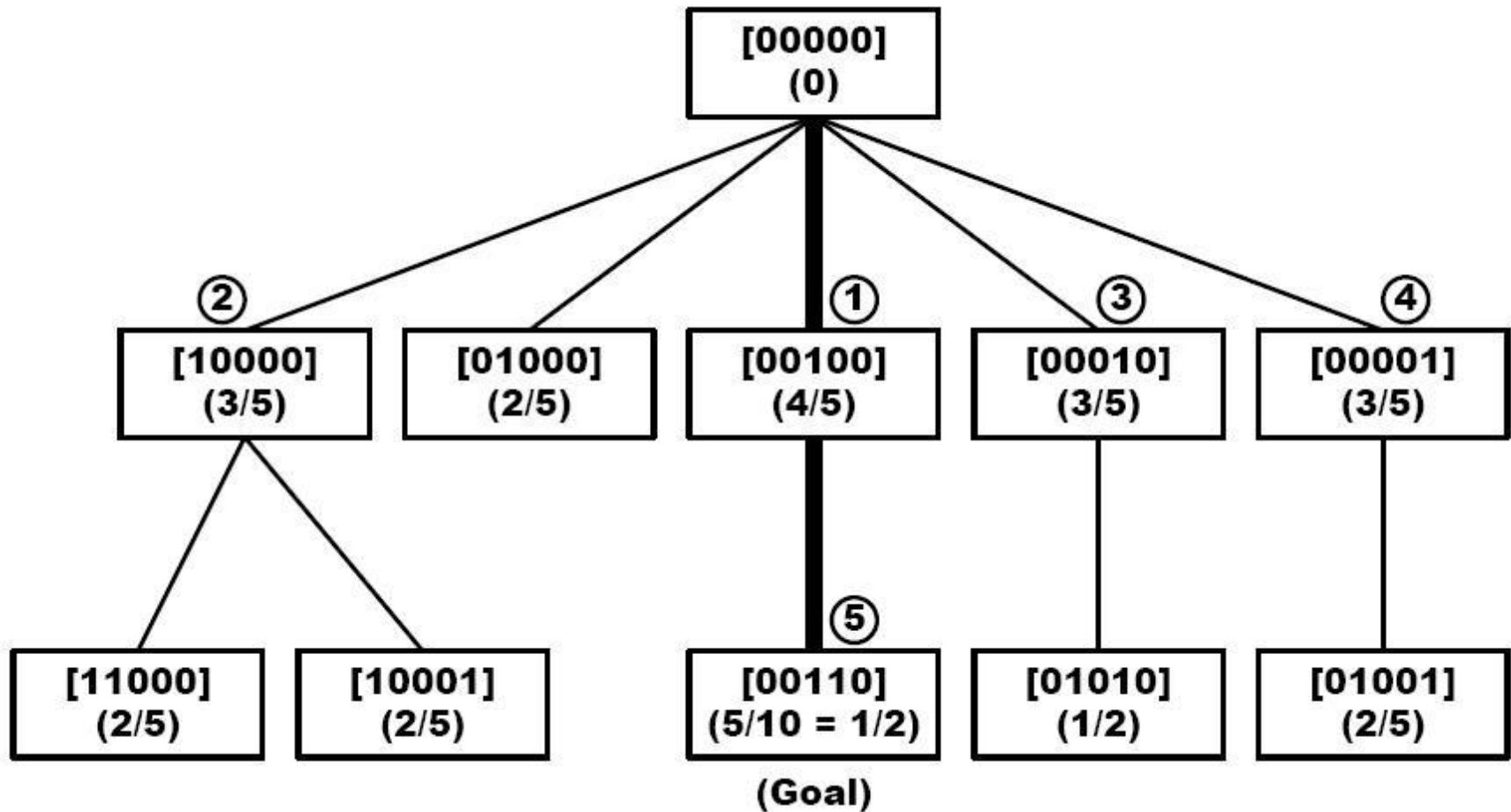


A* Algorithm

- ▶ Principle
 - ▶ Best First Search
- ▶ Advantages
 - ▶ Deterministic
 - ▶ First Solution is Optimal Solution
- ▶ Disadvantages
 - ▶ Large Bus Systems



A* Algorithm – 5 Bus Example



A* Depth Search Method

- ▶ **Principle**

- ▶ Reduce Data Searched

- ▶ **Advantages**

- ▶ Reduced Execution Time of A*
 - ▶ Ability to Adjust Depth

- ▶ **Disadvantages**

- ▶ (Sub) Optimal Solutions
 - ▶ Depth Affects Execution Time
 - ▶ Data Loss



A* Restricted List Method

- ▶ **Principle**

- ▶ Maintains List of Best Options

- ▶ **Advantages**

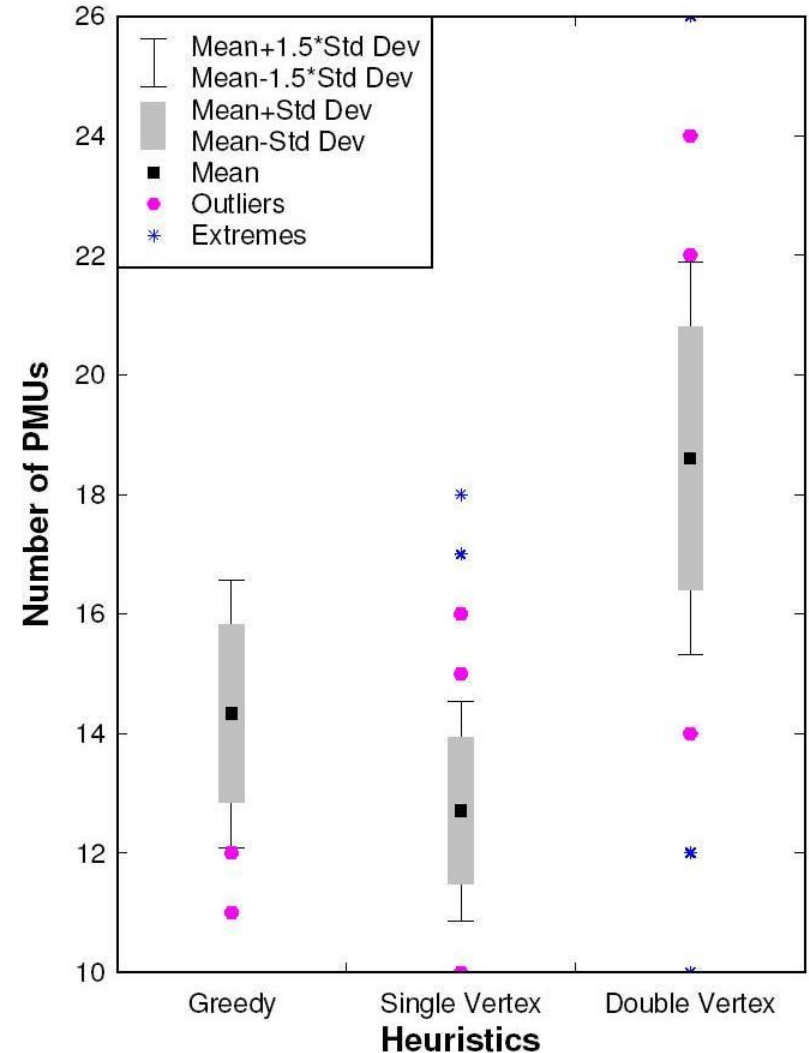
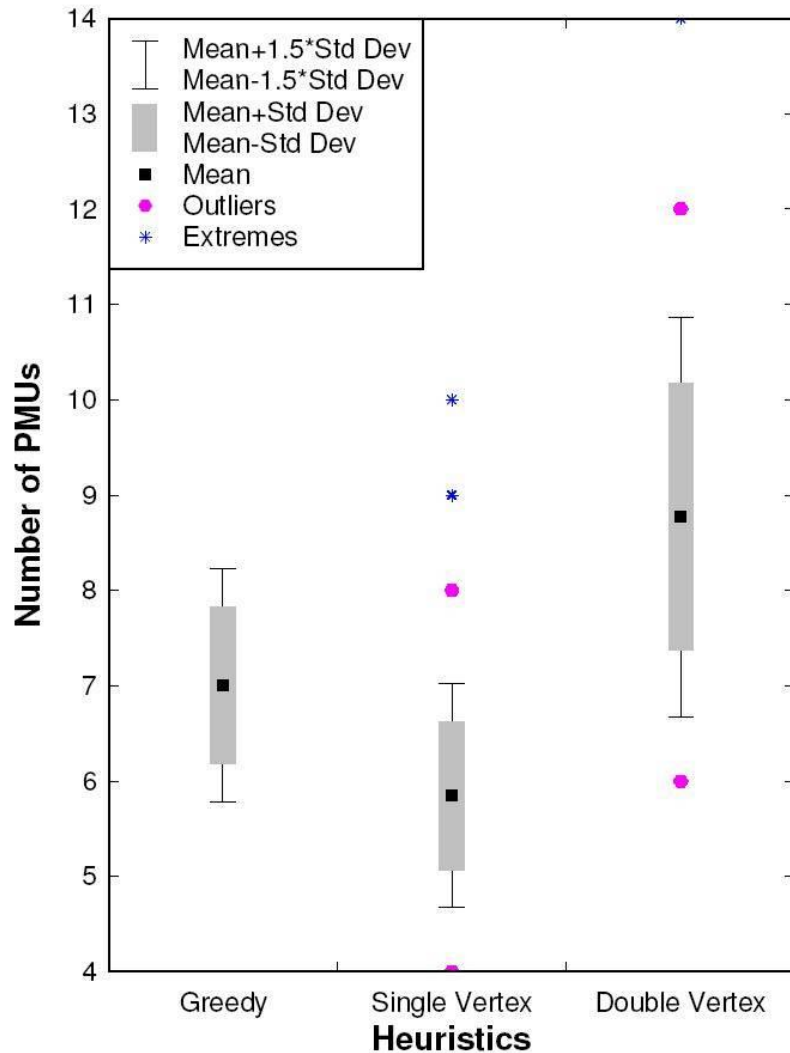
- ▶ Reduced Storage Required
 - ▶ Minimal Search Time

- ▶ **Disadvantages**

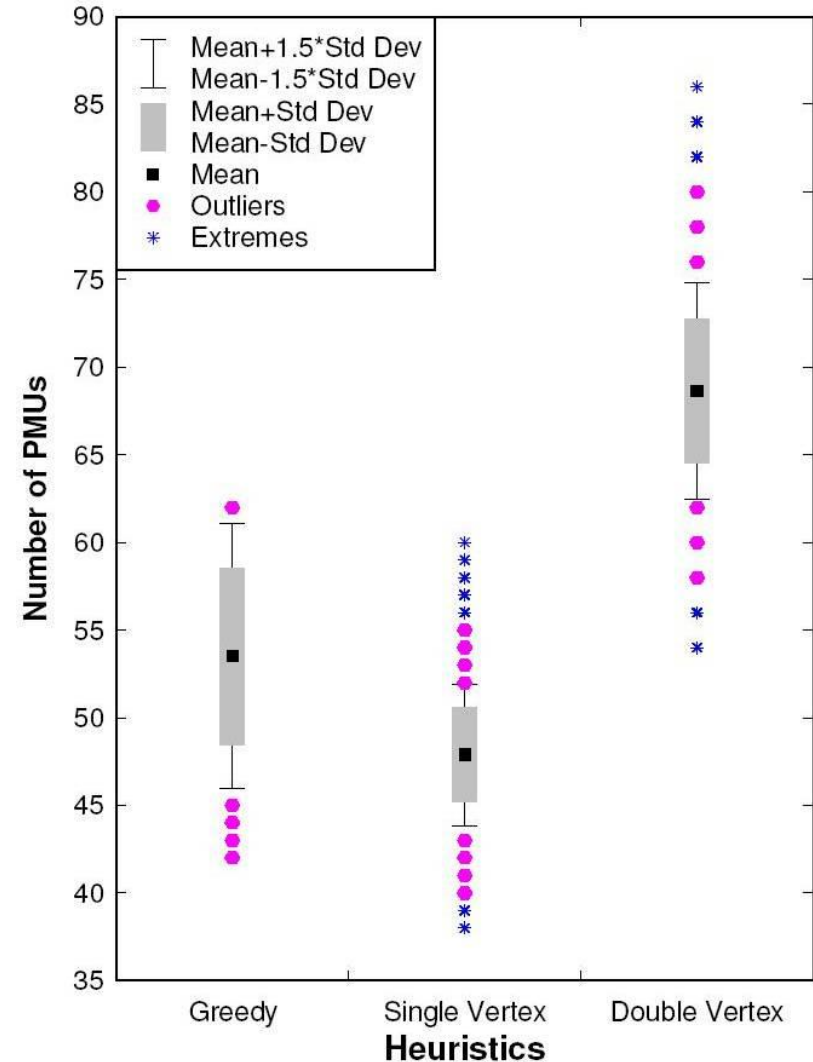
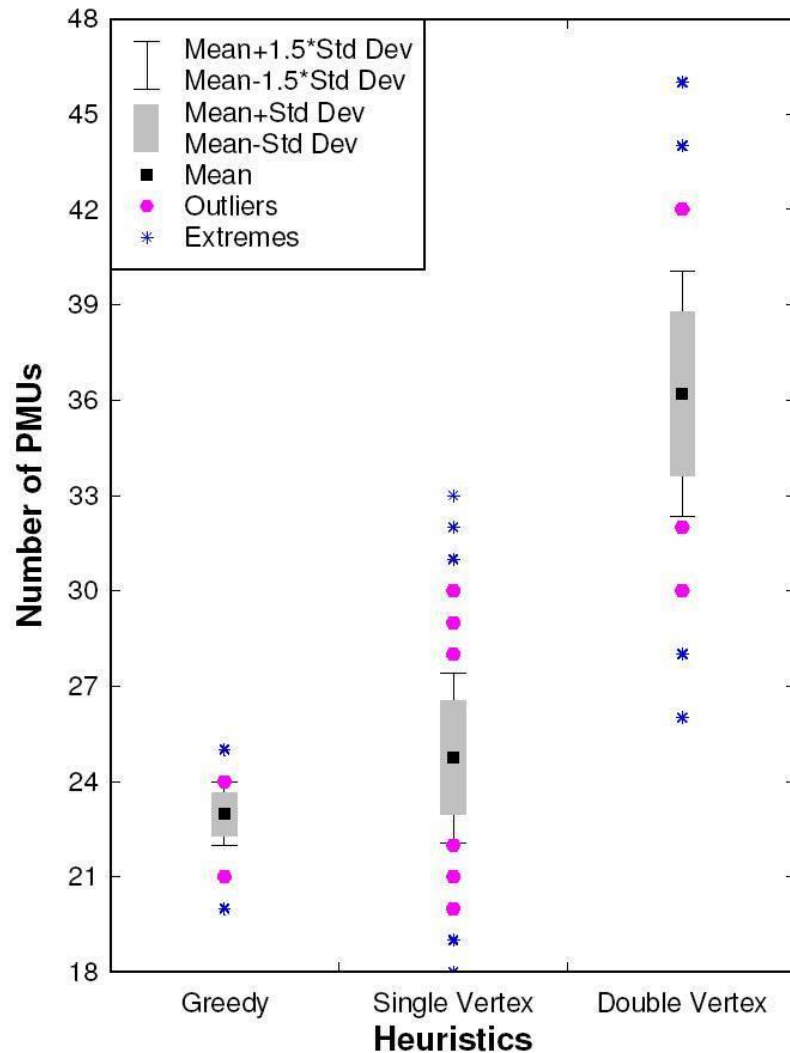
- ▶ (Sub) Optimal Solutions
 - ▶ Data Loss



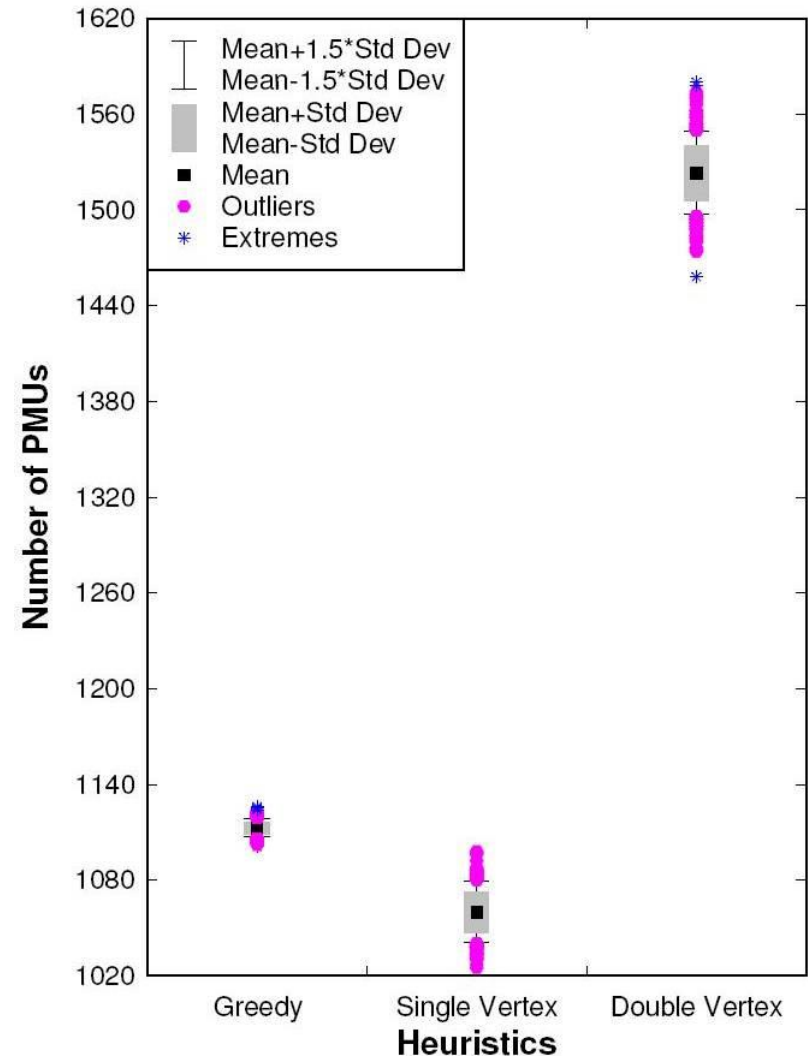
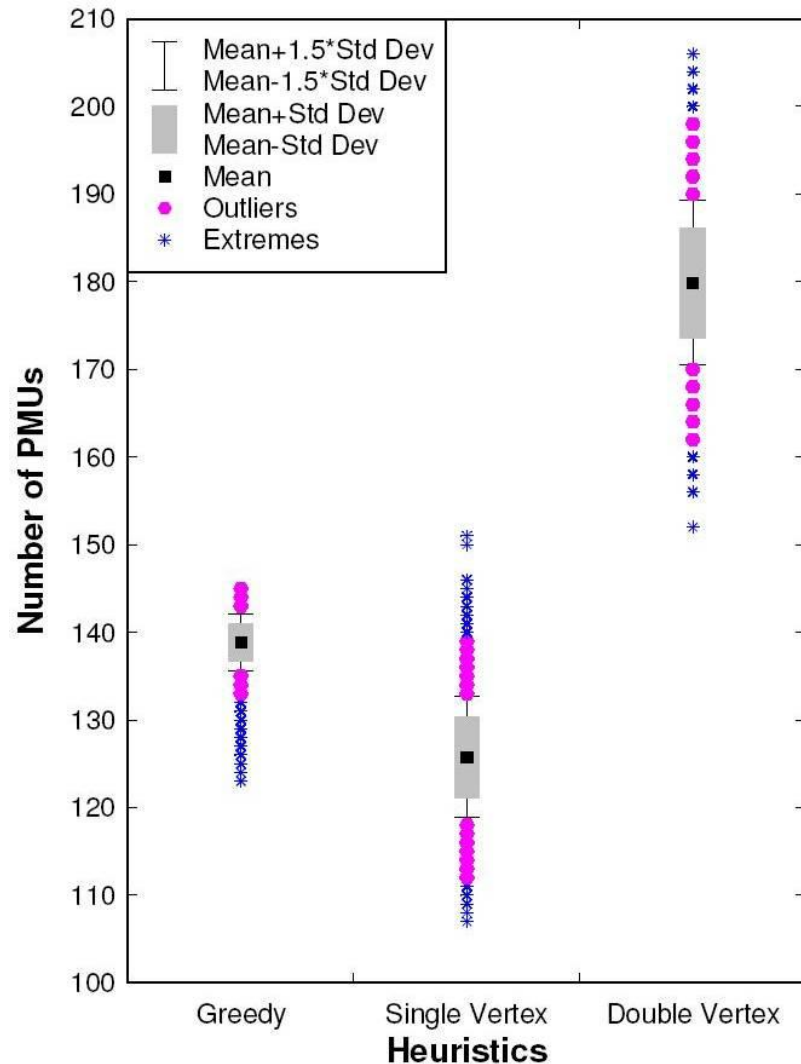
Non-Deterministic Results: 14 & 30 Bus



Non-Deterministic Results: 57 & 118 Bus



Non-Deterministic Results: 300 & 2383 Bus



NON-DETERMINISTIC HEURISTICS RUN-TIME RESULTS PER TRIAL IN SECONDS

Bus System	Heuristics		
	Greedy	Single Vertex	Double Vertex
14-bus	0.000372	0.000365	0.000287
30-bus	0.00082	0.00101	0.00072
57-bus	0.00163	0.00281	0.00189
118-bus	0.00656	0.01231	0.00779
300-bus	0.07086	0.15544	0.08839
2383-bus	17.2198	99.7091	60.8226



A* PLACEMENT RESULTS

Bus Systems	A*	Depth $d = 1$	Method $d = 2$	Restricted List Method
14 bus	4	4	4	4
30 bus	10	10	10	10
57 bus	X	18	18	18
118 bus	X	38	X	38
300 bus	X	110	X	109
2383 bus	X	1054	X	1046



A* RUN-TIME RESULTS IN SECONDS

Bus Systems	A*	Depth Method		Restricted List Method
		$d = 1$	$d = 2$	
14 bus	0.0293	0.0028	0.0047	0.0043
30 bus	4922	0.052	0.095	0.1198
57 bus	X	0.3673	0.4351	0.5417
118 bus	X	2.0369	X	4.18
300 bus	X	4.7814	X	105.36
2383 bus	X	1702.74	X	5033.52



Problems Encountered & Lessons Learned:

▶ Problems Encountered

- ▶ Efficiency on Coding
- ▶ Matlab Programming

▶ Lessons Learned

- ▶ Communication
- ▶ Matlab and LaTeX programming
- ▶ Technical Writing



Budget

- ▶ Combinatorial Optimization - \$15.00
- ▶ Introduction to Graph Theory by Douglas West - \$100.00
- ▶ Graphs and GUIs with MATLAB, 2nd Ed. by Patrick Marchand - \$21.00
- ▶ Posterboard / Rubber Cement - \$8.36
- ▶ Total Cost: \$144.36



Future Work:

- ▶ **Improve Code Efficiency**
 - ▶ Matlab Functions
 - ▶ Storage Arrays
- ▶ **Research and Implementation of Other Algorithms**



Summary

- ▶ **Researched and Implemented Algorithms**
 - ▶ Greedy
 - ▶ Single Vertex
 - ▶ Double Vertex
 - ▶ A^*
 - ▶ Depth Search Method
 - ▶ Restricted List Method
- ▶ **Submit Conference Paper**

